Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Melatonin-Induced Mitigation of Salinity Stress and Enhancement of Barley Productivity

Nauman Akhtar
Agronomy The Islamia University of Bahawalpur
naumanakhtar9290@gmail.com

Muhammad Taimoor Khan
Agronomy The Islamia University of Bahawalpur
muhammadtaimoorkhan92@gmail.com

Muhammad Zeeshan
Agronomy The Islamia University of Bahawalpur
zeeshan.agronomy@gmail.com

Muhammad Abdullah Haroon
Plant breeding & genetics The Islamia university of Bahawalpur
abdharoon1122@gmail.com

Syed Muhammad Mansoor Hassan
Plant Breeding & Genetics The Islamia University of Bahawalpur
smmansoorhassan@gmail.com

Muhammad Naveed
Department of Horticultural Sciences
muhammadnaveed6560@gmail.com

Malik Khawar Khalid
khawarmalik574@gmail.com

ABSTRACT

Melatonin (N-acetyl 5-methoxy tryptophan) is an important hormone and plant growth regulator that promotes the stress tolerance and development of plants, regulates sleep, and acts as an antioxidant in humans. In Pakistan, people consume excessive amounts of salt, which is associated with various health issues, including hypertension and kidney disease. Agricultural production in plant species that have a high tolerance to salinity stress, particularly in barley (*Hordeum vulgare* L.), which ranks fourth in world production, is highly sensitive to salinity stress. Salinity resulted in negative effects on germination percentage, yield, and tolerance to biotic and abiotic stresses, thus posing a serious threat to global food security, particularly in countries like Pakistan. This research evaluates the ameliorative effects of melatonin against salinity

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

stress in barley, focusing on parameters such as plant height, chlorophyll contents, relative water content, water potential, and yield. The objective of this study was to evaluate the potential of the action of melatonin on barley plants under salt stress. The study utilized a fully randomized design featuring a factorial arrangement. Six treatments were conducted involving salinity and Melatonin application, revealing a significant positive correlation between chitosan foliar application and enhanced performance of Barley plants under salt stress conditions. Analysis of findings showed that melatonin significantly improves barley performance in growths under salt stress with the following increases as compared to untreated plants: plant height (20.43%), grain weight (28 %), grain yield (38.82 %), biological yield (16.85 %), harvest index (19.15 %), relative water content (12.74 %), water productivity (14.16 %), and chlorophyll content (86.72 %). The results disclose that melatonin can improve barley growth and productivity through the amending of photosynthesis; avoiding oxidative stress; and facilitating nutrient assimilation, all of which could afford melatonin to remediate for sustainable agriculture and food security in saline soils.

Keywords—

Introduction

Barley (*Hordeum vulgare L.*) is an agriculturally important crop that, due to its adaptability to various climatic conditions, can grow anywhere other than maize or rice (Terefe et al., 2018). It is the fourth most-produced grain after wheat, maize, and rice, being important for food security, animal feed, and the brewing sector (Kumar, 2021). Also, it is the nutritional benefit of supplying elevated fiber and beta-glucans for cholesterol and diabetes regulation. Barley cultivation is presented as an option that can satisfy rising food demand and boost yield and quality, particularly with recent developments (Ahmad et al., 2022). In Pakistan's semi-arid areas, barley is vital; it is sustenance and fodder. Stress-resistant cultivars of high yield, such as Talbinah-21, ensure food security and strengthen rural economies (Ijaz Tabassum, 2021). Barley, which arose in the Fertile Crescent, has been a staple food for over 10,000 years, a climate change specimen, and an important vehicle in the history of human culture (Riehl, 2019; Mascher et al., 2016). However, production and quality are affected and enhanced by salt, aridity, and other problems that limit barley; these problems also make barley more resilient under severe circumstances. These challenges are still investigated with genetic breeding and agronomic methods (Zeng et al. 2018; Riehl 2019). In Pakistan, issues such as soil salinity, particularly in Khyber Pakhtunkhwa, and the management of saline-sodic soils impede agricultural development. However, sustainable production is limited by methods such as 'on-farm seed priming,' which has increased yields under stress, but at an economic cost (Khan et al., 2000). Out of the four principal crops in the world, barley is one of these, the others being wheat, maize, and rice, with regular global production of 147 million tons per year in 2021, a trend down from that of 1990 (Liu and Li 2022). The European Union dominates barley production, surpassing 52 million tonnes each year. In Pakistan, barley was cultivated on 60,000 hectares during the 2017-2018 period, producing 58,000 tons with an average

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

yield of 0.95 tonnes per hectare, far lower than the global average of 3 tonnes per hectare. To satisfy the monthly requirement of 100,000 tonnes, Pakistan imports 40,000 tonnes (Naeem et al., 2022). Land degradation, resulting from deforestation, overgrazing, and inadequate irrigation, jeopardizes soil fertility, food security, and biodiversity. Global initiatives such as Sustainable Development Goal 15.3 advocate for sustainable techniques aimed at restoring degraded areas (Stavi and Lal, 2015). In Pakistan, insufficient irrigation in Punjab and Sindh results in soil salinization, diminishing agricultural productivity. Proposed solutions encompass integrated water management, salt-tolerant crops, and conservation agriculture (Ulain et al., 2022). An abiotic challenge with serious implications for global agriculture is salt stress, which adversely affects soil, ionic equilibrium, and uptake of nutrients by the plant, finally leading to reduced crop growth and yields (Arshad et al., 2021). In particular, salinization is particularly severe in arid regions where the lack of irrigation practice makes it worse. Invariably, the remedies employ expensive management techniques such as leaching salts or using gypsum (Daba and Qureshi, 2021). In Punjab and Sindh, Pakistan, soils are already salt-affected, specifically in the Indus Basin Irrigation System, and the existing irrigation challenges have led to significant degradation in crop productivity, e.g., wheat and rice. The development of salt-tolerant crop varieties, integrated moisture supply methods, and the use of biochemical soil amendments have been proposed alongside salt-tolerant crop varieties as part of the proposed solutions that are required for the recovery of soil and attestation of food security (Iqbal et al., 2019). Overall, around 20% of arable land and 33% of irrigated regions are salt-affected, and climate change makes this problem worse. Salt-tolerant crops, the use of improved methods of irrigation, and the implementation of sustainable practices to reduce impacts (Machado and Serralheiro, 2017) were seen as effective strategies. Growth regulator melatonin (N-acetyl 5-methoxy tryptophan) increases the stress tolerance of plants through the improvement of photosynthesis and antioxidant activity. It also aids in crop resilience in agricultural settings, specifically in the cereals barley and wheat, in the face of salinity and drought stress (Arnao and Hernández-Ruiz, 2018). In this context, Yang et al. (2022) explore the function of melatonin in supporting barley (Hordeum vulgare L.) yield subjected to salinity stress based on its effect on growth, yield, chlorophyll, and associated processes physiology, and molecular. It aims to determine the optimal methods for the application of melatonin to improve barley productivity in saline environments.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Materials and Methods

The experiment was conducted at the Islamia University of Bahawalpur, Pakistan. Treatments consisted of two salinity levels (0 mM NaCl as control and 150 mM NaCl to induce salinity stress) and three Melatonin concentrations (0 µM as control, 15 µM, and 30 µM), making a total of six treatment combinations. Before sowing, soil samples were collected from depths of 0–15 cm and 15–30 cm using a soil auger, labeled, and sent to the Soil and Water Laboratory of the Regional Agricultural Research Institute (RARI), Bahawalpur, for physicochemical analysis (Table 2.1).

Sandy loam soil was collected from the Agronomy Field at the Islamia University of Bahawalpur, Punjab, Pakistan. The soil was prepared properly by breaking the clods, getting rid of stones and stubble, and filling the plastic pots of 15x18 cm. The seeds of 'Talbinah-21' barley were manually sown in each pot on December 2, 2023. In the research period (from December 2023 to April 2024), the highest recorded temperature was 31°C, while the lowest recorded temperature was 18°C. The irrigation was given twice a week at the rate of 400 mL per pot. Weeds were controlled manually by hoeing, and harvesting was done on 27th April, 2024. Sodium chloride (NaCl) was used for salt stress treatments. Based on the calculation, 150 mM NaCl required 8.775 g dissolved in 1 liter of water, and for the 500 mL used per pot, 4.38 g was prepared. For 8 pots, a total of 35.04 g NaCl was required. The salt was weighed, dissolved in a small amount of water, and mixed into a 500 mL solution for foliar application. Control pots received 500 mL of plain water. The parameters studied were plant height at maturity (cm), 100-grain weight (g), grain yield (g/pot), biological yield (g/pot), harvest index (%), relative water content, leaf water potential (ψw), and chlorophyll content.

Table 2.1. Physicochemical analysis of the experimental soil

Characteristics		Status	Values
Texture	Sand (%)	Sandy loam	54
	Silt (%)		32
	Clay (%)		14
PH		Medium alkaline	8.42
EC (dSm^{-1})		Non-saline	0.68
N (%)		Low	0.044
P_2O_5 (ppm)		Low	6
K_2O (ppm)		Medium	149
Organic Matter		Low	0.46
$CaCO_3$		Low	2.12

Statistical Analysis

The experiment was designed as a Complete Randomized Design (CRD Factorial) with three replications. Recorded data were subjected to analysis of variance (Two-way ANOVA) using the software Statistix8.1. Means were compared by Tukey HSD at $p \leq 0.05$

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Results

Effect of Salinity Stress on Plant Height of Barley

Plant growth and physiological parameters of Barley were observed, showing significant differences between different treatments of Melatonin and salinities. Significant differences existed between plant height for different treatments. Salinity effects were observed with a 14.10% decrease under 150 mM NaCl without Melatonin. It was shown that Melatonin had growth promotion effects with increases of 8.78% and 12.45% at 15 and 30 µM concentrations, respectively, when saline was not used. Concerning the salt stress effect, under this stress condition, the 16.41%, 12.77%, and 20.43% increases were recorded in the absence of Melatonin, 15 µM Melatonin, and 30 µM Melatonin, respectively, indicating the importance of Melatonin in alleviating salt stress and improving plant growth as depicted in Figure 3.1.

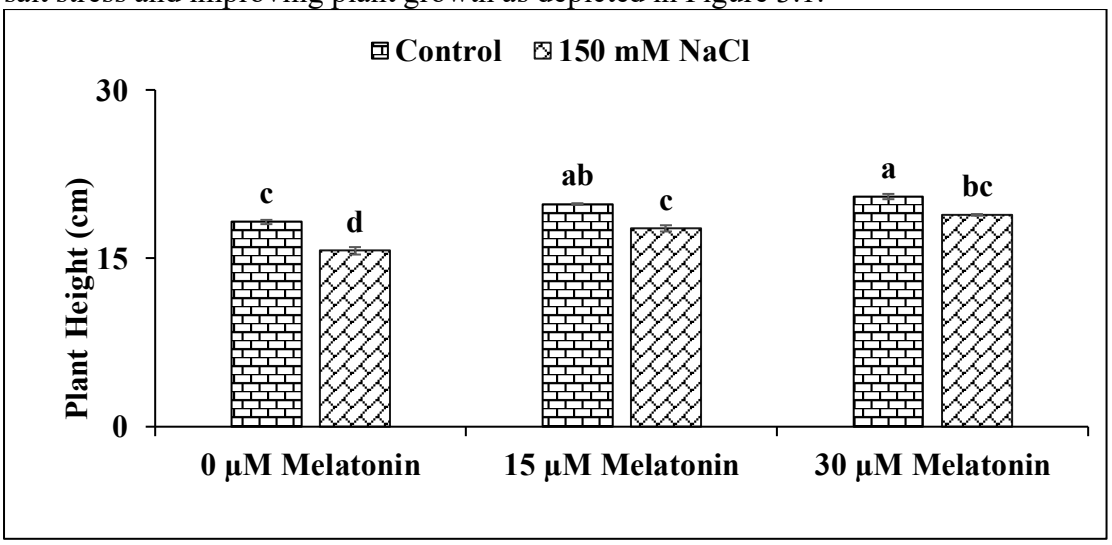


Fig 3.1 Plant Height (cm) of Barley

Effect of Salinity Stress on 100-Grain Weight of Barley

There were highly significant differences between treatments in 100-grain weight produced by the barley plants. There was an increase of 30.76% for 30 µM Melatonin as compared with 0 µM (control), which demonstrated a positive effect on grain development. A 3.84% reduction, on the other hand, was observed in the salinity of control plants (without Melatonin) at 150 mM NaCl. The percentage increase in salt-affected plants was found as 26.92% greater in plants under salt stress than in Melatonin-treated plants (salt stress + 15 µM Melatonin). In comparison to the unstressed saline control, both 15 and 30 µM Melatonin produced 26.8% and 28% higher grain weight under salt stress, indicating that Melatonin mitigated salt stress and stimulated grain development (Figure 3.2).

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

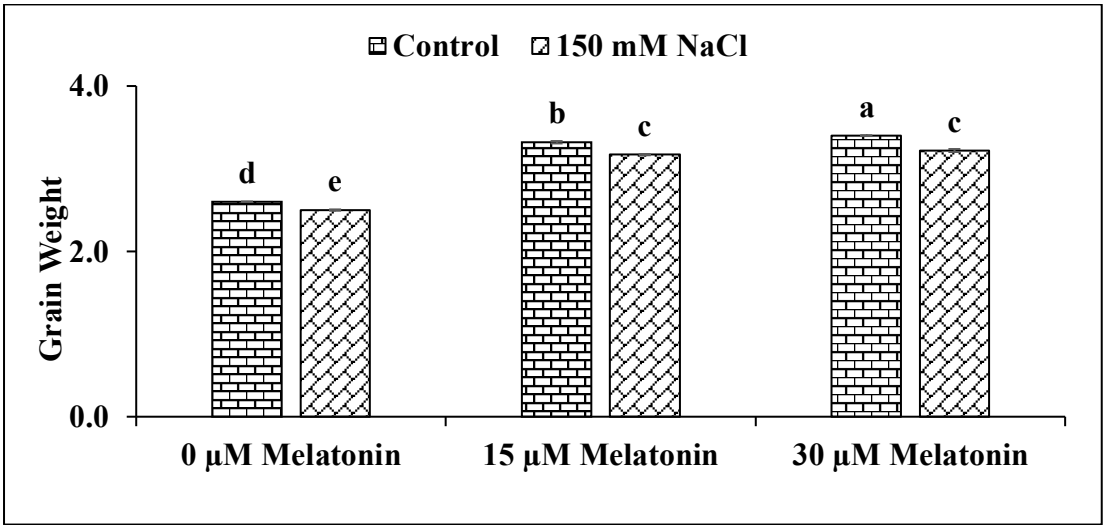


Fig 3.2 100 Grains weight of Barley

Effect of Salinity Stress on Grain Yield of Barley

The grain yield of barley plants varied significantly across treatments. A 15.56% decrease was seen at 150 mM NaCl without Melatonin, which showed the effect of salt stress. But, when it is under normal conditions, application of 15µM and 30µM of Melatonin increased the grain yield by 23.84% and 31.12%, respectively, indicating the beneficial effect of Melatonin. Without Melatonin, under NaCl stress, there was 18.89% increase in grain yield, indicating the effect of salt stress. Salt stress conditions saw further increases of 16.07%, 38.82% of 15 µM and 30 µM Melatonin concentrations respectively, highlighting the impact of Melatonin on alleviating stress and improving yield as illustrated in Figure 3.3.

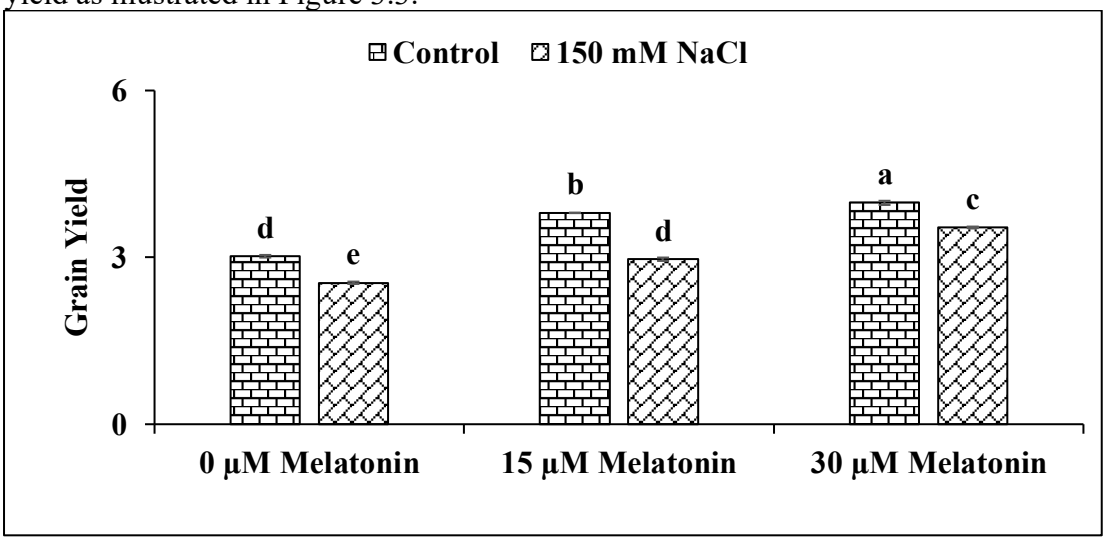


Fig 3.3 Grain Yield of Barley

Effect of Salinity Stress on Biological Yield of Barley

The biological yield of barley plants varied significantly among treatments. No addition of Melatonin was seen to cause a decrease in plant growth of 7.61% at 150 mM NaCl, which shows the effect of salt stress. In contrast, under the non-stress condition,

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

Melatonin 15 µM and 30 µM boosted the biological yield by 10.91% and 14.09%, respectively, underscoring the beneficial effect of Melatonin. Biological yield showed an 8.24% increment in 15 µM Melatonin under salt stress as compared to the untreated plants. Further increments by 0.74% to 16.85% was observed when applied to the plant with 15 µM to 30 µM of Melatonin, respectively, indicating the importance of Melatonin in the reduction of salt stress and enhancement of biological yield as shown in Fig. 3.4.

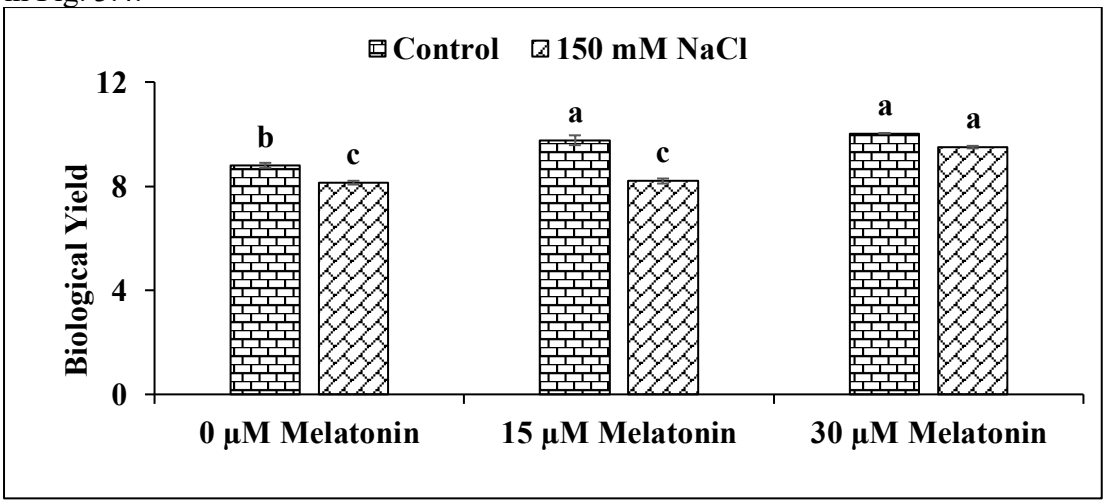


Fig 3.4 Biological Yield of Barley

Effect of Salinity Stress on Harvest Index of Barley

The harvest index of barley plants varied significantly across treatments. A decrease of 8.88% was observed under 150 mM NaCl without Melatonin, indicating the negative impact of salt stress. In contrast, applying 15 µM and 30 µM Melatonin under non-stress conditions increased the harvest index by 13.51% and 15.58%, respectively, demonstrating Melatonin's positive effect. Under salt stress, a 9.75% increase occurred without Melatonin, while 15 µM and 30 µM Melatonin applications resulted in increases of 15.73% and 19.15%, respectively, highlighting Melatonin's role in mitigating salt stress and improving the harvest index, as shown in Figure 3.5.

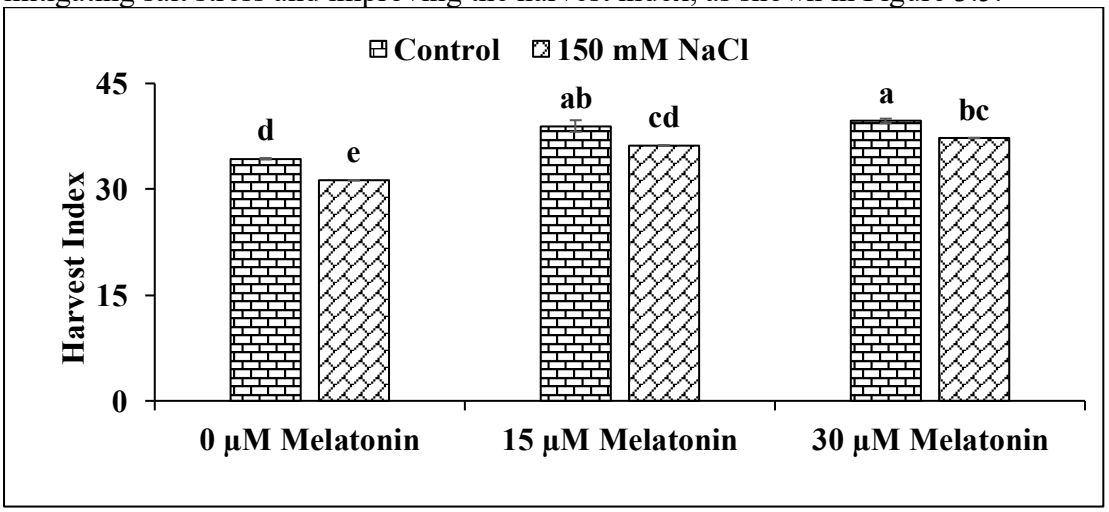


Fig 3.5 Harvest Index (%) of Barley

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Effect of Salinity Stress on Relative Water Content of Barley

The relative water content (RWC) of barley plants varied significantly across treatments. Under 150 mM NaCl without Melatonin, RWC decreased by 16.83%, highlighting salt stress effects. A 20.23% increase in RWC was observed under salt stress compared to the control, indicating salt-induced physiological responses. Melatonin treatments improved RWC under both normal and stress conditions. There was 1.71% increase with 15 µM Melatonin and an 8.82% increase with 30 µM Melatonin, indicating the importance of water retention as affected by Melatonin. It is worth noticing that under salt stress, the RWC showed 3.86% increase in 15 µM Melatonin and 12.74% increase in 30 µM Melatonin, depicting the effectiveness of Melatonin in protecting the plants against potential dehydration, as shown in Figure 3.6.

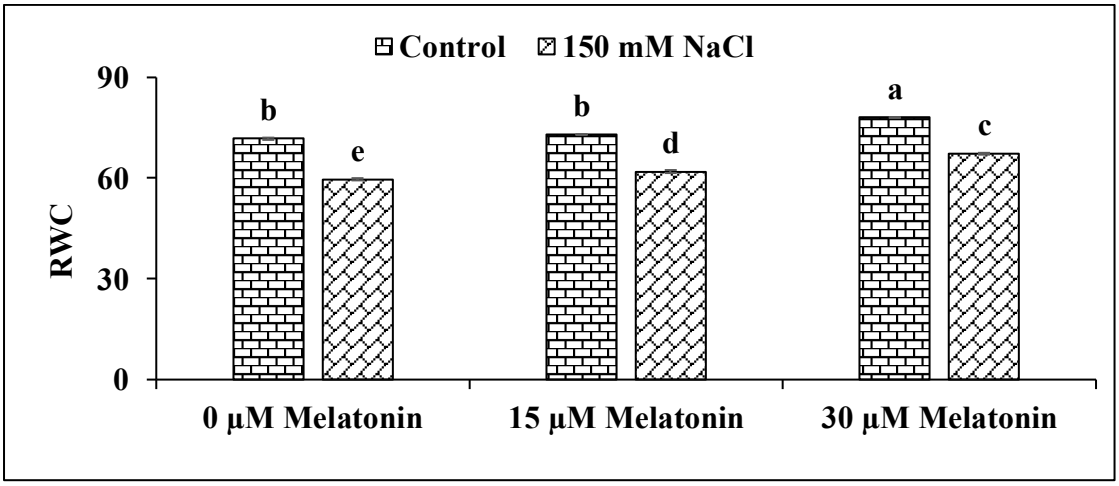


Fig 3.6 The Relative Water Content of Barley

Effect of Salinity Stress on Water Potential of Barley

As illustrated in this figure, the WPP of barley plants was greatly affected by various treatments, which showed the importance of Melatonin and NaCl in plant physiology. In salt stress, WPP was 23.77% lower than the control situation, showing that this plant species can suffer from NaCl to a great extent. WPP, on the other hand, fell by 19.20% when NaCl was 150 mM in the absence of Melatonin, underlining the negative impacts of salt stress. In non-stress conditions, the WPP at 15 and 30 µM of Melatonin increased by 6.71% and 8.49%, respectively, indicating its favorable effect. As observed in Figure 3.7, WPP increased by 5.49% in 15 µM Melatonin and 14.16% in 30 µM Melatonin under salt stress, which is an indication of the positive effect of Melatonin in mitigating salt stress and increasing WPP.

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

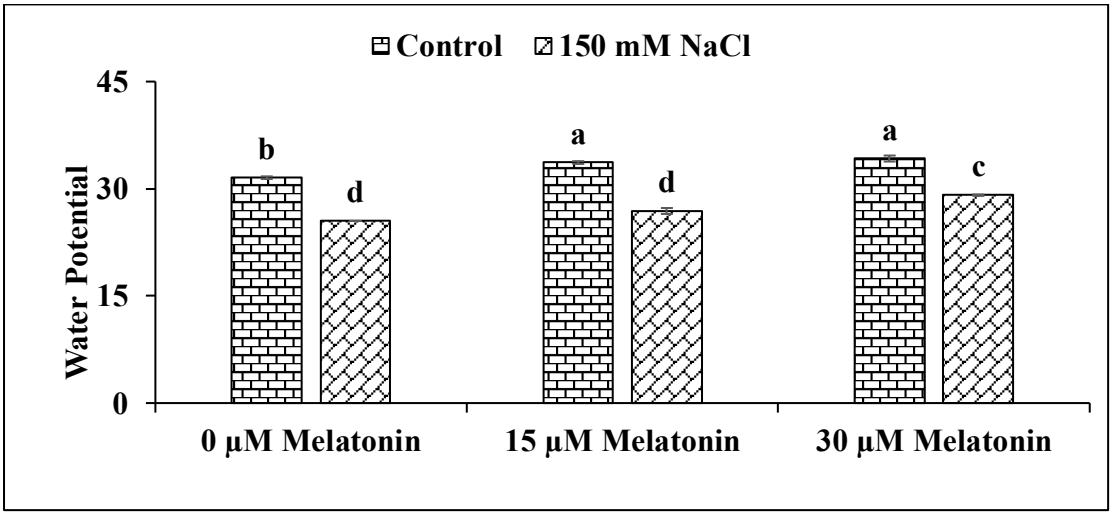


Fig 3.7 Water Pressure Potential of Barley

Effect of Salinity Stress on Chlorophyll Contents of Barley

There were significant differences between the treatments with regard to barley plant chlorophyll content. Under salt stress conditions, severe growth reduction of 54.63% was seen in the absence of Melatonin, and 30 µM Melatonin treatment induced a remarkable growth increase of 237.5%, which is typical of the role of Melatonin in salt stress mitigation. The chlorophyll content under non-stress conditions was 67.01% and 77.31% higher at 15 and 30 µM Melatonin, respectively, reflecting its positive impact. Additionally, 15 µM and 30 µM Melatonin doses caused a significant increase relative to the control, positively demonstrating the utilisation of Melatonin in increasing the levels of chlorophyll in the salt-stressed plants (Figure 3.8).

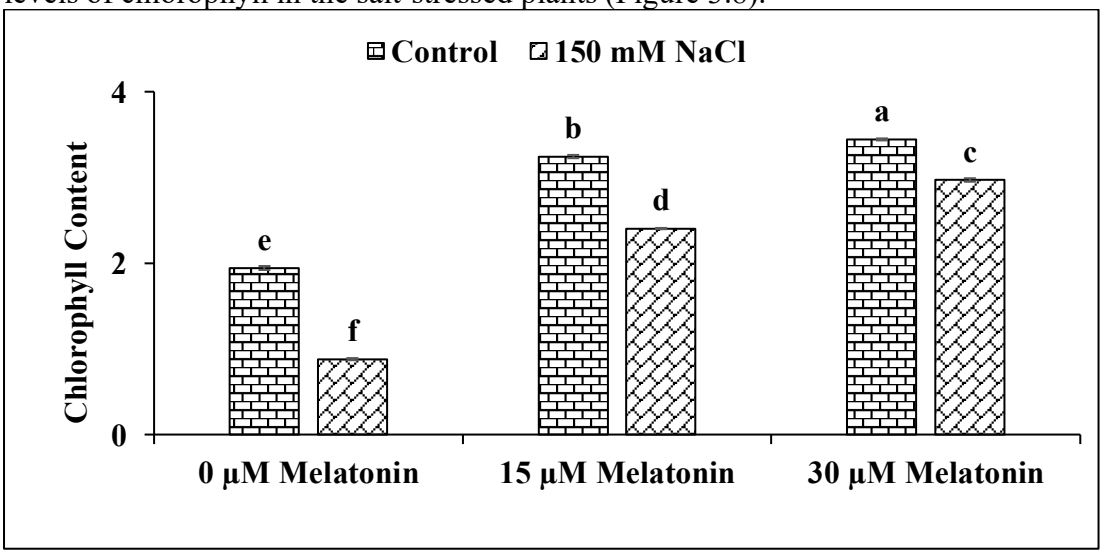


Fig 3.8 Chlorophyll Content of Barley

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 3 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Discussion

Barley is very sensitive to salinity stress, which, among other effects, affects plant growth, chlorophyll content, and grain yield through induced restriction in the uptake of important ions such as potassium and calcium, which are required for cell activities and photosynthesis. (Y. Ma et al., 2019. High levels of 'salt stress' result in the production of reactive oxygen species (ROS), causing oxidative damage, reduced stomatal conductance, and loss of chlorophyll. Together, these all lead to decreased efficiency of the photosynthetic machinery, and plant health and yield are dramatically affected. (Hirasawa et al., 2017) (Hessini et al., 2015). Plant height showed a reduction under NaCl and an increase in 30 µM melatonin conditions to 14.10% and 12.45%, respectively, indicating that melatonin might have mitigated the salt stress. Melatonin is known to boost antioxidants, photosynthesis, root elongation, and the uptake of nutrients, resulting in better growth in stressful conditions (Kaya and Ashraf, 2021). The 100-grain weight, as an extremely important measurement of crop productivity, showed a substantial difference between the various treatments. The results showed that melatonin 30 µM resulted in a 30.76% positive increase, while in the salt stress without melatonin condition, it resulted in a negative increase of 3.84%. Melatonin enhances the grain and weight, alleviates stress effects by improving nitrogen metabolism, photosynthetic efficiency, and the activity of antioxidant enzymes. (Murphy et al., 2018). It also regulates the production of growth hormones such as zeatin and gibberellic acid, improves carbon assimilation, and decreases oxidative stress, which positively contribute to seed filling and yield. (Ahmad et al., 2021). Different salt stress and/or melatonin applications had a 23.84%, 31.12%, 16.07% and 38.82% negative and positive effect, respectively, on grain yield. Melatonin makes a difference in the yields and increases the antioxidant activity, photosynthesis, and nitrogen uptake. (Zhang et al., 2022). Under salt stress, biological yield strongly improved in barley in response to the treatment with melatonin, there was a 16.85%, compared to 7.61% decrease, at 30 µM. It improves growth through increased antioxidant capacity and N assimilation. (Chang et al., 2021). Furthermore, the harvest index got 19.15% better when melatonin was used, as it induces a reduction of oxidative stress and enhances the root-shoot biomass ratio (Zhang et al., 2021). Under salt stress, melatonin led to a 20.23% rise in the relative water content (RWC) and a 23.77% rise in the water potential (WPP), thereby advancing the use of water and the osmo protectants. (Ali et al., 2021). Provides hydration and membrane integrity to cells and helps to distribute water. (Campos et al., 2019). Melatonin maintained the chlorophyll concentration, which was decreased by 54.63% when salt stress was present in the absence of melatonin, by deterring the degradation of chloroplasts and improving the photosynthetic process. (Wei et al., 2022).

Conclusion

Barley is affected negatively by salinity stress since it reduces chlorophyll content, affects photosynthesis, and has a low harvest index. Conclusively, using melatonin reduces these negative effects on grain yield and HI%, promotes chlorophyll synthesis, and preserves cell membrane integrity. By enhancing the tolerance of barley to salinity, melatonin ensures high production in regions with high salinity levels, increases the

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

area of cultivatable land to feed the growing population, and supports sustainable agriculture to meet the growing global food needs.

References

Ahmad, J., Tabassum, M. I., Owais, M., Riaz, M., Nadeem, M., Abdullah, M., Shair, H., Gulnaz, S., Ghafoor, I., Javed, A., & Mahmood, A. (2022). Talbinah-21: Pakistan's first hull-less, high-yielding, and lodging-tolerant barley variety. *Plant Cell Biotechnology and Molecular Biology, 23*, 1–9. https://doi.org/10.56557/pcbmb/2022/v23i29-307765

Ahmad, S., Kamran, M., Zhou, X., Ahmad, I., Meng, X., Javed, T., Iqbal, A., Wang, G., Su, W., Wu, X., Ahmad, P., & Han, Q. (2021). Melatonin improves the seed-filling rate and endogenous hormonal mechanism in grains of summer maize. *Physiologia Plantarum, 172*(2), 1059–1072. https://doi.org/10.1111/ppl.13282

Ali, M., Kamran, M., Abbasi, G. H., Saleem, M. H., Ahmad, S., Parveen, A., Malik, Z., Afzal, S., Ahmar, S., Dawar, K. M., Ali, S., Alamri, S., Siddiqui, M. H., Akbar, R., & Fahad, S. (2021). Melatonin-induced salinity tolerance by ameliorating osmotic and oxidative stress in the seedlings of two tomato (*Solanum lycopersicum* L.) cultivars. *Journal of Plant Growth Regulation, 40*(5), 2236–2248. https://doi.org/10.1007/s00344-020-10273-3

Arnao, M. B., & Hernández-Ruiz, J. (2018). Melatonin and its relationship to plant hormones. *Annals of Botany, 121*(2), 195–207. https://doi.org/10.1093/aob/mcx114

Arshad, M., Ullah, M. K., Iqbal, A., Tariq, M. U., & Waqas, A. (2021). Effect of saline water irrigation and dilution of salts on water management in green pepper. *Pakistan Journal of Engineering and Technology, 4*(4), 15–22. https://doi.org/10.51846/vol4iss4pp15-22

Campos, C. N., Ávila, R. G., de Souza, K. R. D., Azevedo, L. M., & Alves, J. D. (2019). Melatonin reduces oxidative stress and promotes drought tolerance in young *Coffea arabica* L. plants. *Agricultural Water Management, 211*, 37–47. https://doi.org/10.1016/j.agwat.2018.09.025

Chang, T., Zhao, Y., He, H., Xi, Q., Fu, J., & Zhao, Y. (2021). Exogenous melatonin improves growth in hulless barley seedlings under cold stress by influencing the expression rhythms of circadian clock genes. *PeerJ, 9*. https://doi.org/10.7717/peerj.10740

Daba, A. W., & Qureshi, A. S. (2021). Review of soil salinity and sodicity challenges to crop production in the lowland irrigated areas of Ethiopia and its management strategies. *Land, 10*(12), 1377. https://doi.org/10.3390/land10121377

Hessini, K., Ferchichi, S., Ben Youssef, S., Werner, K. H., Cruz, C., & Gandour, M. (2015). How does salinity duration affect growth and productivity of cultivated barley? *Agronomy Journal, 107*(1), 174–180. https://doi.org/10.2134/agronj14.0281

Hirasawa, T., Sato, K., Yamaguchi, M., Narita, R., Kodama, A., Adachi, S., Ookawa, T., & Sato, K. (2017). Differences in dry matter production, grain production, and photosynthetic rate in barley cultivars under long-term salinity. *Plant Production Science, 20*(3), 288–299.

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

https://doi.org/10.1080/1343943X.2017.1343647

Ijaz Tabassum, M. (2021). JAU-17: A first high-yielding malting barley variety suitable for marginal lands of Punjab. *Open Access Journal of Agricultural Research, 6*(3). https://doi.org/10.23880/oajar-16000275

Iqbal, S., Basra, S. M. A., Afzal, I., Wahid, A., Saddiq, M. S., Hafeez, M. B., & Jacobsen, S. E. (2019). Yield potential and salt tolerance of quinoa on salt-degraded soils of Pakistan. *Journal of Agronomy and Crop Science, 205*(1), 13–21. https://doi.org/10.1111/jac.12290

Kaya, C., & Ashraf, M. (2021). Nitric oxide is required for aminolevulinic acid-induced salt tolerance by lowering oxidative stress in maize (*Zea mays*). *Journal of Plant Growth Regulation, 40*(2), 617–627. https://doi.org/10.1007/s00344-020-10126-z

Khan, A., Azam, M., & Khan, M. (2000). Grain yield and economic effect of NP fertilizers application on dryland barley. *Pakistan Journal of Biological Sciences, 3*(5), 816–818. https://doi.org/10.3923/pjbs.2000.816.818

Kumar, U. (2021). Popular article on millets. *December*.

Liu, J., & Li, X. (2022). Impact of extreme weather disasters on China's barley industry under the background of trade friction—Based on the partial equilibrium model. *Foods, 11*(11), 1570. https://doi.org/10.3390/foods11111570

Ma, Y., Wang, P., Chen, Z., Gu, Z., & Yang, R. (2019). NaCl stress on physio-biochemical metabolism and antioxidant capacity in germinated hulless barley (*Hordeum vulgare* L.). *Journal of the Science of Food and Agriculture, 99*(4), 1755–1764. https://doi.org/10.1002/jsfa.9365

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae, 3*(2). https://doi.org/10.3390/horticulturae3020030

Mascher, M., Schuenemann, V. J., Davidovich, U., Marom, N., Himmelbach, A., Hübner, S., Korol, A., David, M., Reiter, E., Riehl, S., Schreiber, M., Vohr, S. H., Green, R. E., Dawson, I. K., Russell, J., Kilian, B., Muehlbauer, G. J., Waugh, R., Fahima, T., … Stein, N. (2016). Genomic analysis of 6,000-year-old cultivated grain illuminates the domestication history of barley. *Nature Genetics, 48*(9), 1089–1093. https://doi.org/10.1038/ng.3611

Murphy, B. R., Jadwiszczak, M. J., Soldi, E., & Hodkinson, T. R. (2018). Endophytes from the crop wild relative *Hordeum secalinum* L. improve agronomic traits in unstressed and salt-stressed barley. *Cogent Food and Agriculture, 4*(1), 1–10. https://doi.org/10.1080/23311932.2018.1549195

Naeem, M., Minhas, W. A., Hussain, S., Ul-Allah, S., Farooq, M., Farooq, S., & Hussain, M. (2022). Barley-based cropping systems and weed control strategies influence weed infestation, soil properties, and barley productivity. *Agriculture (Switzerland), 12*(4). https://doi.org/10.3390/agriculture12040487

Riehl, S. (2019). Barley in archaeology and early history. *Oxford Research Encyclopedia of Environmental Science*, 1–2. https://doi.org/10.1093/acrefore/9780199389414.013.219

Stavi, I., & Lal, R. (2015). Achieving zero net land degradation: Challenges and opportunities. *Journal of Arid Environments, 112*, 44–51.

Online ISSN 3007-3197
Print ISSN 3007-3189
http://amresearchreview.com/index.php/Journal/about

https://doi.org/10.1016/j.jaridenv.2014.01.016

Terefe, D., Desalegn, T., & Ashagre, H. (2018). Effect of nitrogen fertilizer levels on grain yield, N uptake, and N use efficiency of malt barley (*Hordeum vulgare* L.) varieties at Wolmera District, Central Highland of Ethiopia. *International Journal of Research Studies in Agricultural Sciences, 4*(4), 2454–6224. http://dx.doi.org/10.20431/2454-6224.0412002

Ulain, Q., Ali, S. M., Shah, A. A., Iqbal, K. M. J., Ullah, W., & Tariq, M. A. U. R. (2022). Identification of soil erosion-based degraded land areas by employing a geographic information system—A case study of Pakistan for 1990–2020. *Sustainability (Switzerland), 14*(19). https://doi.org/10.3390/su141911888

Wei, L., Zhao, H., Wang, B., Wu, X., Lan, R., Huang, X., Chen, B., Chen, G., Jiang, C., Wang, J., Liu, Y., & Zheng, Q. (2022). Exogenous melatonin improves the growth of rice seedlings by regulating redox balance and ion homeostasis under salt stress. *Journal of Plant Growth Regulation, 41*(6), 2108–2121. https://doi.org/10.1007/s00344-021-10417-z

Yang, X., Chen, J., Ma, Y., Huang, M., Qiu, T., Bian, H., Han, N., & Wang, J. (2022). Function, mechanism, and application of plant melatonin: An update with a focus on the cereal crop, barley (*Hordeum vulgare* L.). *Antioxidants, 11*(4). https://doi.org/10.3390/antiox11040634

Zeng, X., Guo, Y., Xu, Q., Mascher, M., Guo, G., Li, S., Mao, L., Liu, Q., Xia, Z., Zhou, J., Yuan, H., Tai, S., Wang, Y., Wei, Z., Song, L., Zha, S., Li, S., Tang, Y., Bai, L., … Tashi, N. (2018). Origin and evolution of Qingke barley in Tibet. *Nature Communications, 9*(1), 1–11. https://doi.org/10.1038/s41467-018-07920-5

Zhang, Y., Yu, T., Ma, W., Dayananda, B., Iwasaki, K., & Li, J. (2021). Morphological, physiological, and photophysiological responses of critically endangered *Acer catalpifolium* to acid stress. *Plants, 10*(9), 1958. https://doi.org/10.3390/plants10091958

Zhang, G., Yan, Y., Zeng, X., Wang, Y., & Zhang, Y. (2022). Quantitative proteomics analysis reveals proteins associated with high melatonin content in barley seeds under NaCl-induced salt stress. *Journal of Agricultural and Food Chemistry, 70*(27), 8492–8510. https://doi.org/10.1021/acs.jafc.2c00466